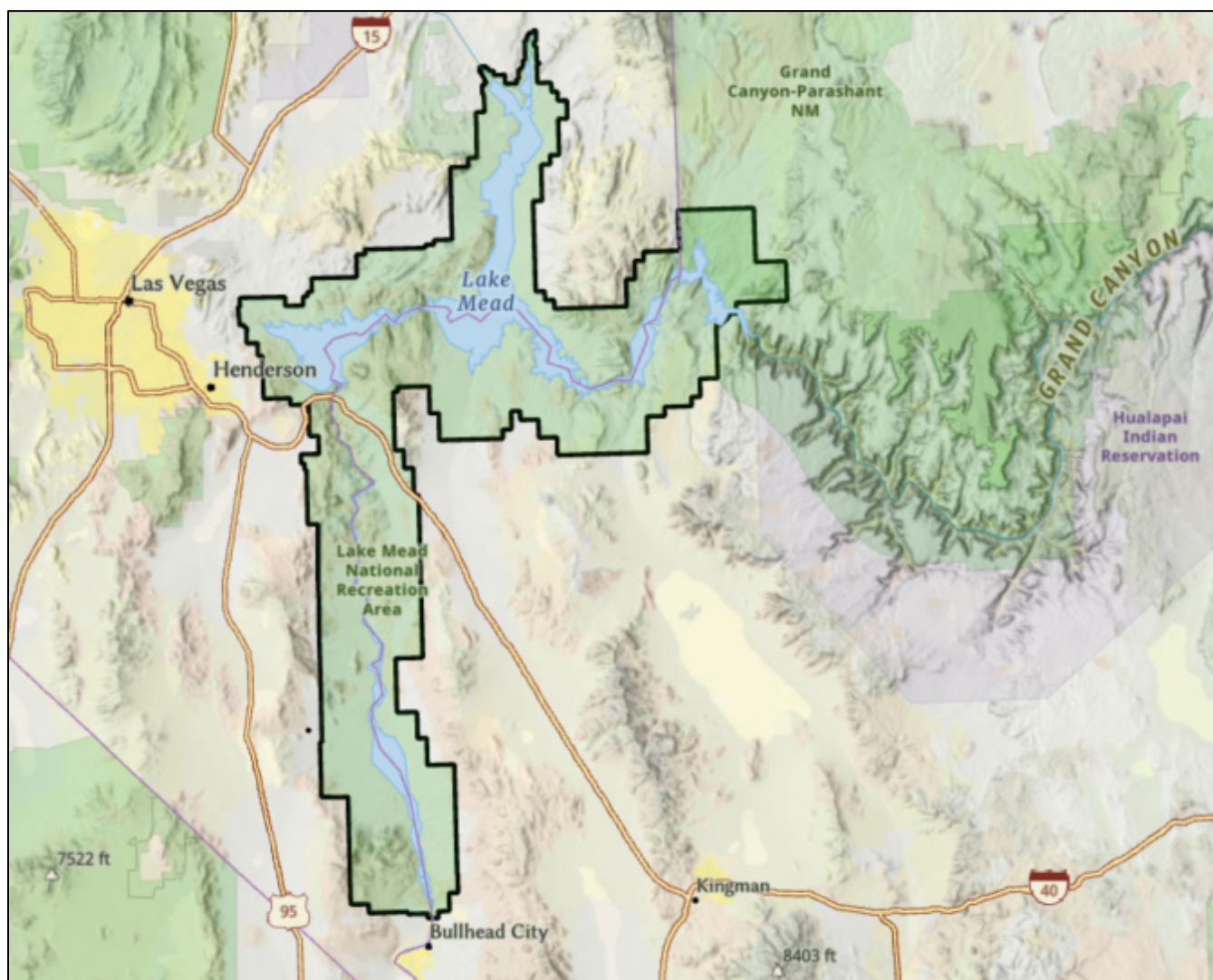




Exploring Spatial Patterns of Overflights at Lake Mead National Recreation Area

Natural Resource Report NPS/LAKE/NRR—2023/2489



ON THE COVER

Map of Lake Mead National Recreation Area

Map service layer credits: Esri, CGIAR, USGS, HERE, Garmin, FAO, NOAA, Bureau of Land Management, EPA, and NPS

Exploring Spatial Patterns of Overflights at Lake Mead National Recreation Area

Natural Resource Report NPS/LAKE/NRR—2023/2489

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Abstract

This study explored spatial patterns of overflights at Lake Mead National Recreation Area (LAKE). Overflights were analyzed from August 16th, 2020 to September 30th, 2021 using Automatic Dependent Surveillance-Broadcast (ADS-B) and radar data from L3Harris. The first phase of analysis focused on all overflights and found a high concentration of overflights above LAKE. The second phase of analysis focused on low-level overflights that fly below 8,500ft mean sea level (MSL) and displays figures for low-level fixed wing single engine, fixed wing multi engine, and rotorcraft. The phase 2 results show different flight patterns across aircraft types. The third phase of analysis removed all overflights known to not be air tours. Kernel density analysis was conducted using waypoints segmented into 500ft above ground level (AGL) altitude intervals, which showed that the density of overflights varied by altitude interval and the 4,000–4,500ft AGL range had the highest density of overflights above LAKE. This altitude interval also had the highest number of waypoints. This information can be used for planning and management purposes and this study serves as a resource for future research that intends to use more advanced analytics.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic information systems

LAKE: Lake Mead National Recreation Area

MSL: Mean sea level

NPS: National Park Service

NPATMA: National Parks Air Tour Management Act

Introduction

Lake Mead National Recreation Area (LAKE) is America's first and largest national recreation area (1.5 million acres). LAKE is located near Las Vegas along the border of Nevada and Arizona and follows the Colorado River corridor. It is comprised of two reservoirs, Lake Mead and Lake Mohave, which were created when the Hoover Dam and Davis Dam were constructed. The two reservoirs are connected via the Colorado River. Lying within LAKE are nine designated wilderness areas and three of the four desert ecosystems found in the United States (Mojave Desert, Great Basin Desert, and Sonoran Desert). LAKE visitors typically enjoy water recreation (e.g., boating, swimming, and fishing), hiking, biking, camping, horseback riding, hunting, and scenic driving. The expanse of LAKE and the desert surroundings are also popular to view for air tours.

In 2019, commercial air tour operators reported conducting a total of 5,218 air tours at LAKE (National Park Service, 2021), which was the fourth highest frequency of air tours in the national park system. The National Parks Air Tour Management Act of 2000 (NPATMA) (Public law 106-81) requires the National Park Service (NPS) and Federal Aviation Administration to develop an air tour management plan for those parks and tribal lands where operators have applied to conduct commercial air tours, with the exception of Grand Canyon National Park and all national parks in the State of Alaska (Beeco & Joyce, 2019). Unique to LAKE, NPATMA has a specific exception for air tours that are traveling from the Las Vegas area (specifically Clark County, Nevada) to Grand Canyon National Park. These 'transportation flights' are considered exempt from the requirements of NPATMA. The purpose of this report is to provide examination of the spatial patterns of all overflights at LAKE, which may assist in the development of an Air Tour Management Plan for air tours at LAKE.

As of January 1, 2020, the Federal Aviation Administration (FAA) requires all aircraft that enter designated airspace to be equipped with ADS-B technology (see 14 CFR § 91.225 and 14 CFR § 91.227) (FAA, 2020). Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States. The western portion of LAKE is located under designated Class B airspace, which means ADS-B is required on aircraft that fly above that portion of LAKE.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (FAA, 2018). This study analyzed overflights using both ADS-B technology as well as radar to track flights that flew above LAKE. Overflight data were obtained in partnership with L3Harris. The data discussed in this report span from August 16th, 2020 to September 30th, 2021 and include 411 days of data.

After the data were screened of flights known not to be air tours, the data set comprised of 12,669 flights. A total of 5,218 air tour flights were reported at LAKE for 2019. This discrepancy was expected because the data were collected for 411 days instead of a full calendar year and transportation flights traveling to Grand Canyon National Park may have analytically appeared similar to air tours. Additionally, the combination of ADS-B and radar data would be expected to capture nearly all flights that occurred over the park during these 411 days.

Methods

Data Collection

Aircraft tracking data were collected and purchased from L3Harris (<https://www.l3harris.com/>). The acquired data were formatted as polyline shapefiles for geographic information systems (GIS) analysis. Polyline shapefiles are comprised of point data (waypoints) which contain further information, such as latitude, longitude, and altitude. Waypoint information must be extracted from polyline shapefiles using GIS software. The data consisted of a continuous collection from August 16th, 2020 to September 30th, 2021. The polyline shapefiles were imported into ArcGIS Pro version 2.8.3. The shapefiles included the following flight metadata: flight start time, flight end time, flight duration, and tail number. These shapefiles were projected to WGS 1984 Universal Transverse Mercator Zone 11N, which uses a linear unit of a meter. To explore the spatial patterns of overflights at LAKE, analysis was conducted in three phases. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, CGIAR, USGS, HERE, Garmin, FAO, NOAA, Bureau of Land Management, EPA, and NPS.

Altitude expressed in mean sea level (MSL) refers to the altitude of an aircraft above sea level, regardless of the terrain below it, whereas altitude expressed in above ground level (AGL) is a measurement of the distance between the ground surface and the aircraft. For this report, Phase 1 and Phase 2 use MSL, while Phase 3 uses AGL. This is because MSL is better suited for understanding aircraft patterns across a larger space or scale because the baseline (sea level) does not change. However, because Phase 3 includes more detailed examinations of the data, AGL analysis was also used because it better contextualizes how flights undulate over the terrain and associated terrestrial resources and visitors' experiences.

Phase 1 methods

The purpose of the first phase was to explore all overflight paths above LAKE regardless of flight type or altitude. Thus, polyline shapefiles were not cleaned of any flight types nor was an altitude threshold implemented. Four maps were produced. The first map shows overflights from August 16th, 2020 to October 30th, 2020 (late summer). The second map shows overflights from November 1st, 2020 to February 28th, 2021 (fall and winter). The third map shows overflights from March 1st, 2021 to May 31st, 2021 (spring). The fourth map shows overflights from June 1st, 2021 to September 30th, 2021 (summer).

Phase 2 methods

The purpose of the second phase was to understand low-level overflights above LAKE regardless of flight type. Low-level overflights were identified as having an altitude less than 8,500ft MSL. This altitude was chosen because the highest point at LAKE is 5,639ft (Summit Post, 2021), and approximately 3,000ft above the highest point in the park would capture flights that had the greatest impact on the acoustic environment in the park. Lake Mead has a surface elevation of approximately 1,043ft and Lake Mohave has an approximate surface elevation of 643ft (United States Bureau of Reclamation, 2022). To understand flight altitudes, the polyline line shapefiles were converted to point shapefiles using the 'Feature Vertices to Points' geoprocessing tool. Point data with altitudes

above 8,500ft MSL were excluded. Five maps were produced. The first map shows fixed wing single engine (FAA aircraft type #4). The second map shows fixed wing multi engine (FAA aircraft type #5). The last three maps show rotorcraft (FAA aircraft type #6) with MSL altitude ranges of: 1) 0–3,500ft; 2) 3,501–6,000ft; and 3) 6,001–8,500ft.

Phase 3 methods

The purpose of the third phase was to focus on air tours above LAKE by removing all overflights known to not be air tours. The original polyline shapefiles were again converted to point shapefiles. Next, data were cleaned of civil patrol, flights with a straight-line path, and survey flights. Civil patrol flights were removed from analysis because of their infrequent nature and known purpose (i.e., not air tours). Civil patrol flights were identified using the FAA Releasable Database (FAA, 2021) and retrieving all flights that were registered by a government agency (FAA registrant type #5). Flights with straight-line paths were also excluded from analysis because these are flights that travel above LAKE in a direct path towards a destination (e.g., major airlines) and are clearly not air tours. Straight-line flight paths were identified using a sinuosity calculation and then visually inspected. Sinuosity is a measure of how much a linear feature deviates from a straight-line condition and can be calculated as the ratio of total flight path length to the straight-line distance between a flight's initial and final waypoint. A perfectly straight flight path would have a sinuosity of one, but as the number of meanders in the path increases (e.g., the characteristic back and forth of survey flight behavior) sinuosity will begin to approach zero. All overflights that received sinuosity values greater than or equal to 0.80 were visually inspected to validate straight-line flight paths were flown and these were subsequently removed from analysis. Survey flights were also removed from analysis because of their infrequent nature and known flight purpose. Survey flights were identified using visual analysis of flight spatial behavior, which was conducted for all flights. Survey flight behavior can be identified when a flight route consists of consecutive back and forth lateral movements in a parallel progression. Air tour behavior generally consists of flight routes that veer toward sightseeing locations and consist of sporadic S-turns and loops (Beeco & Joyce, 2019). After this cleaning step, the remaining flights are more likely to be air tours, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are air tours is not possible.

Using the point data cleaned of all civil patrol, survey, and straight-line flights, above ground level (AGL) altitudes were determined for every waypoint. A 30-meter digital elevation model (DEM) (United States Geological Survey, 2021) was used to determine AGL altitudes of every waypoint. The AGL altitudes were calculated by subtracting the reported altitudes of the ADS-B logger minus the elevation of the DEM for every point location (x,y) (see Beeco et al., 2020 for exact method). Using a 500ft AGL altitude interval, point data were segmented (0–500ft AGL; 500–1,000ft AGL; 1,000–1,500ft AGL; 1,500–2,000ft AGL; 2,000–2,500ft AGL; 2,500–3,000ft AGL; 3,000–3,500ft AGL; 3,500–4,000ft AGL; 4,000–4,500ft AGL; 4,500–5,000ft AGL) and kernel density analysis was conducted for each altitude interval. Because each altitude interval had different amounts of waypoints, density classifications were normalized across altitude intervals. To do this, the altitude interval with the most waypoints (4,000–4,500ft AGL) was used to normalize density classification, which required two steps. First, the 4,000–4,500ft AGL altitude kernel density was classified using equal interval percentage breaks with five intervals of 20%. These percentage breaks were

determined using the maximum waypoints per square kilometer as the '100%' value. Second, the maximum number of waypoints per each 20% interval were then applied to kernel density classifications for the other altitude intervals. These steps are necessary to ensure density is calculated the same across altitude intervals regardless of the number of waypoints. Two figures were constructed that display kernel density analyses across sequential altitude intervals (beginning with the lowest altitude range). After these steps were accomplished, kernel density outputs were statistically compared for relatedness using the 'Band Collection Statistics' tool which conducted a correlation test.

Next, descriptive analyses were conducted to understand waypoint spatial distribution and quantity across altitude intervals. Descriptive analyses were also conducted to understand number of flights across months, day of the week, and hour of the day.

Results

Results – Phase 1

The research team mapped overflights for all flights ($n=387,741$). Figure 1 shows overflights from August 16th, 2020 to October 30th, 2020 (late summer). Figure 2 shows overflights from November 1st, 2020 to February 28th, 2021 (fall and winter). Figure 3 shows overflights from March 1st, 2021 to May 31st, 2021 (spring). Figure 4 shows overflights from June 1st, 2021 to September 30th, 2021 (summer).

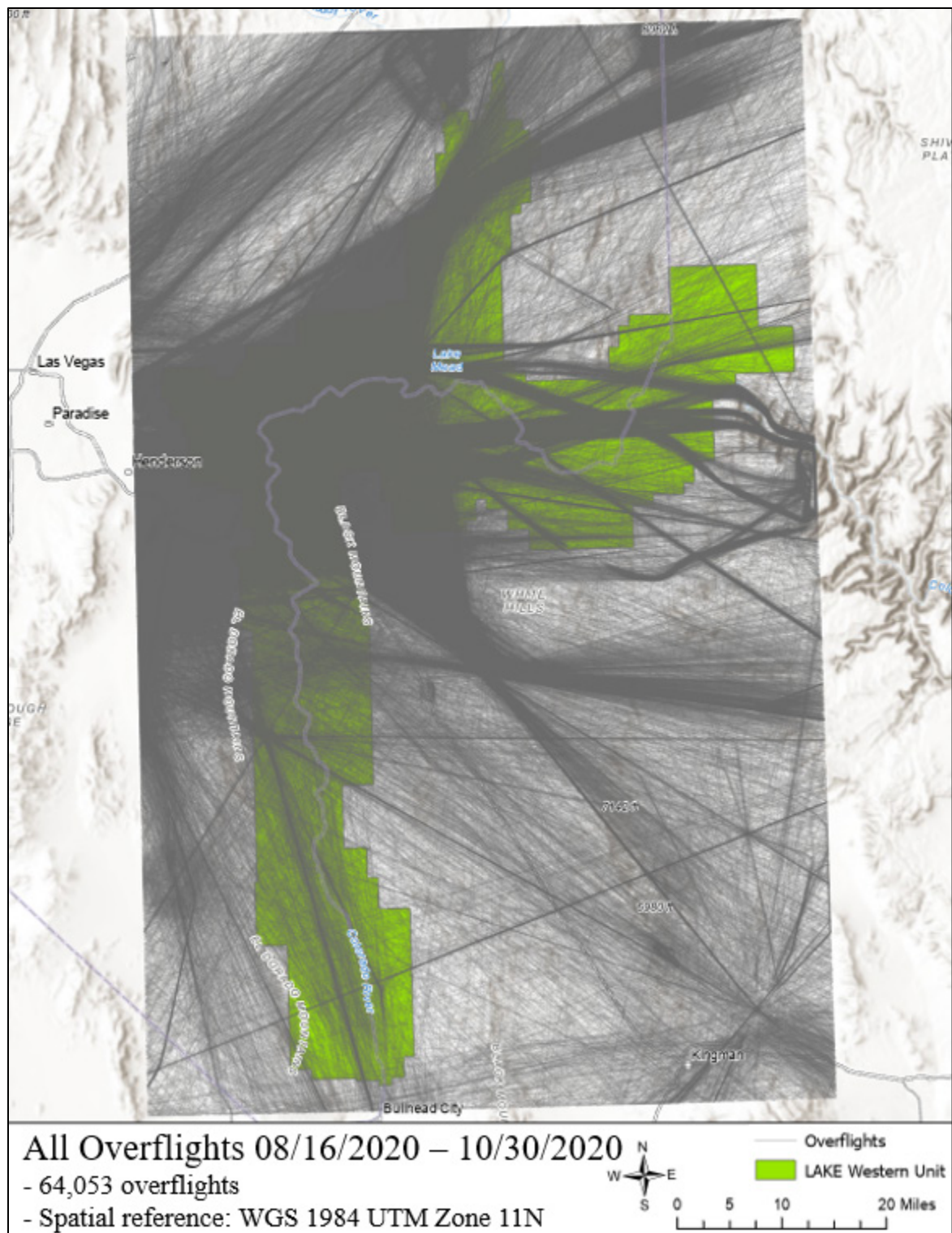


Figure 1. Overflights between August 16th, 2020 to October 30th, 2020.

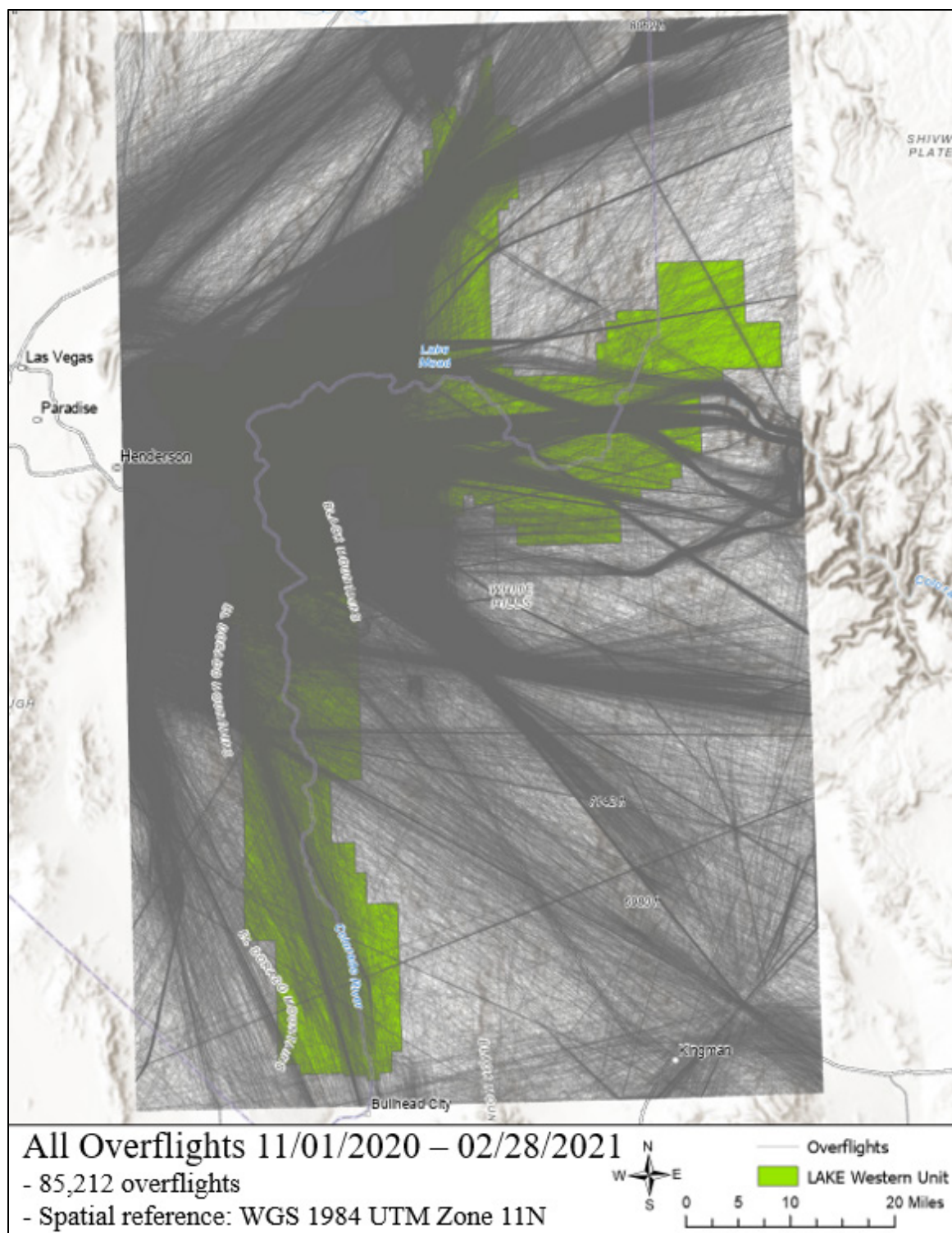


Figure 2. Overflights between November 1st, 2020 to February 28th, 2021.

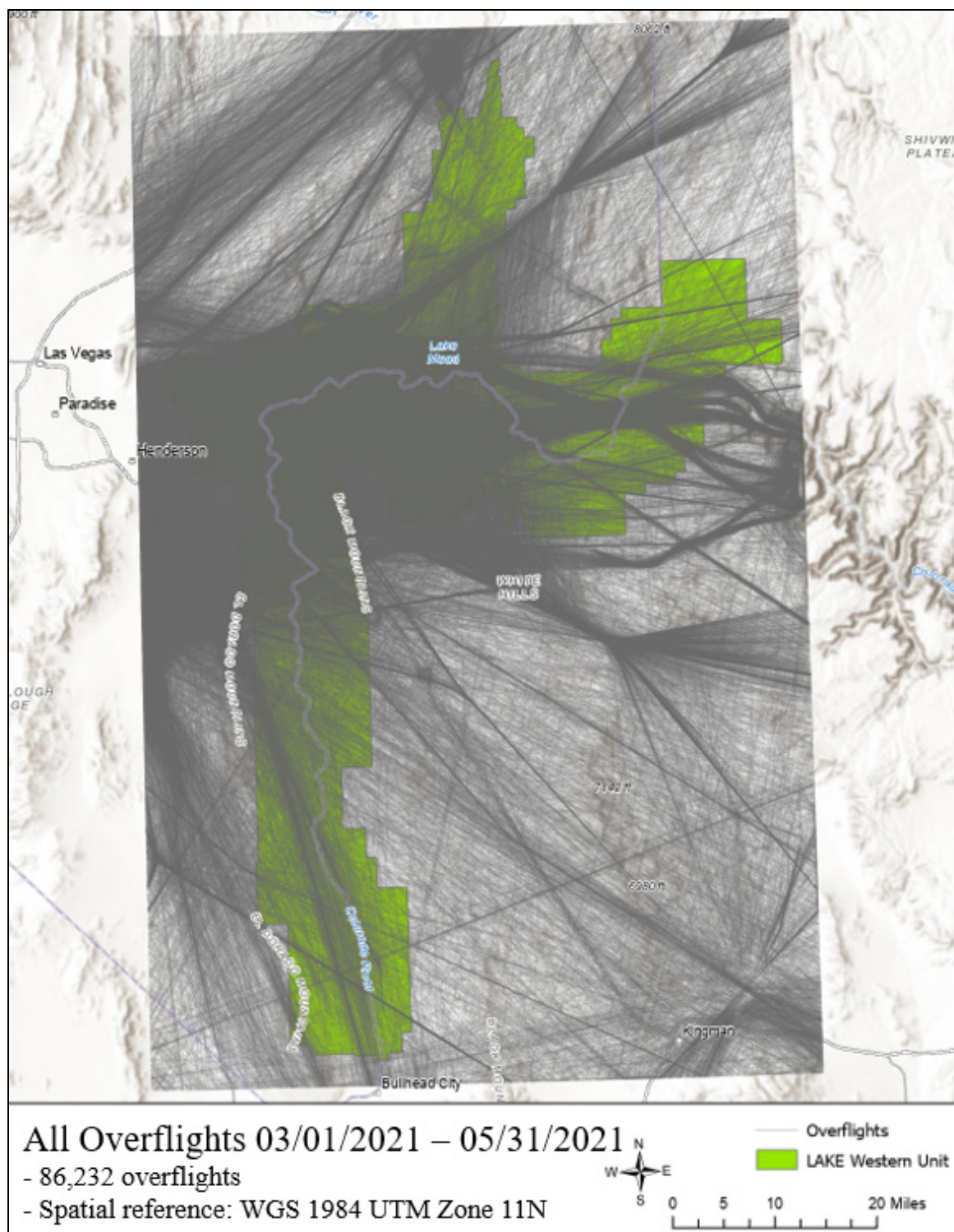


Figure 3. Overflights between March 1st, 2021 to May 31st, 2021.

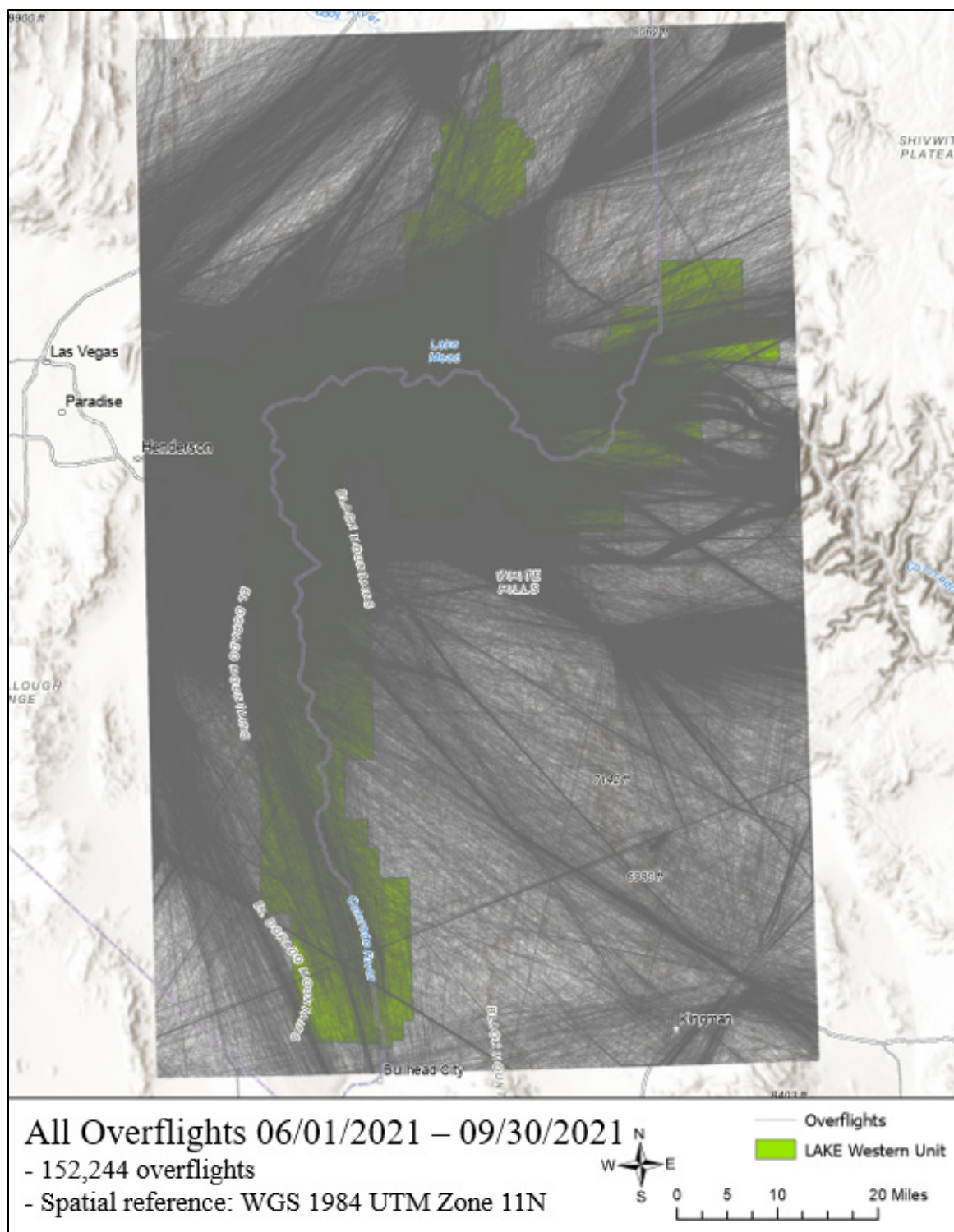


Figure 4. Overflights between June 1st, 2021 to September 30th, 2021.

Results – Phase 2

The research team mapped low-level overflights that flew below 8,500ft MSL regardless of flight type. Figure 5 shows low-level fixed wing single engine overflights. Figure 6 shows low-level fixed wing multi engine overflights. Figure 7 shows low-level rotorcraft overflights that flew at altitudes between 0–3,500ft MSL. Figure 8 shows low-level rotorcraft overflights that flew at altitudes between 3,501–6,000ft MSL. Figure 9 shows low-level rotorcraft overflights that flew at altitudes between 6,001–8500ft MSL.

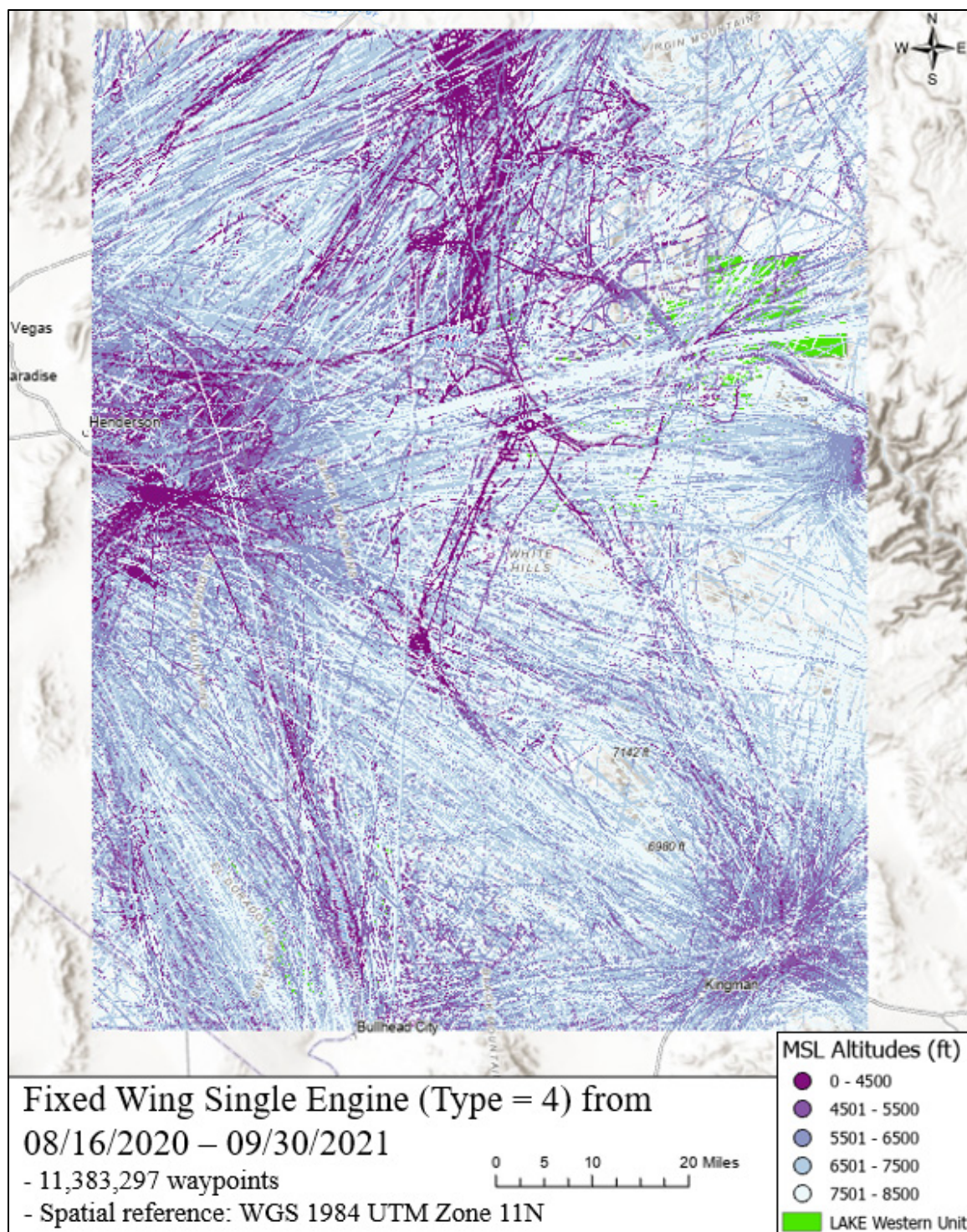


Figure 5. Low-level fixed wing single engine overflights.

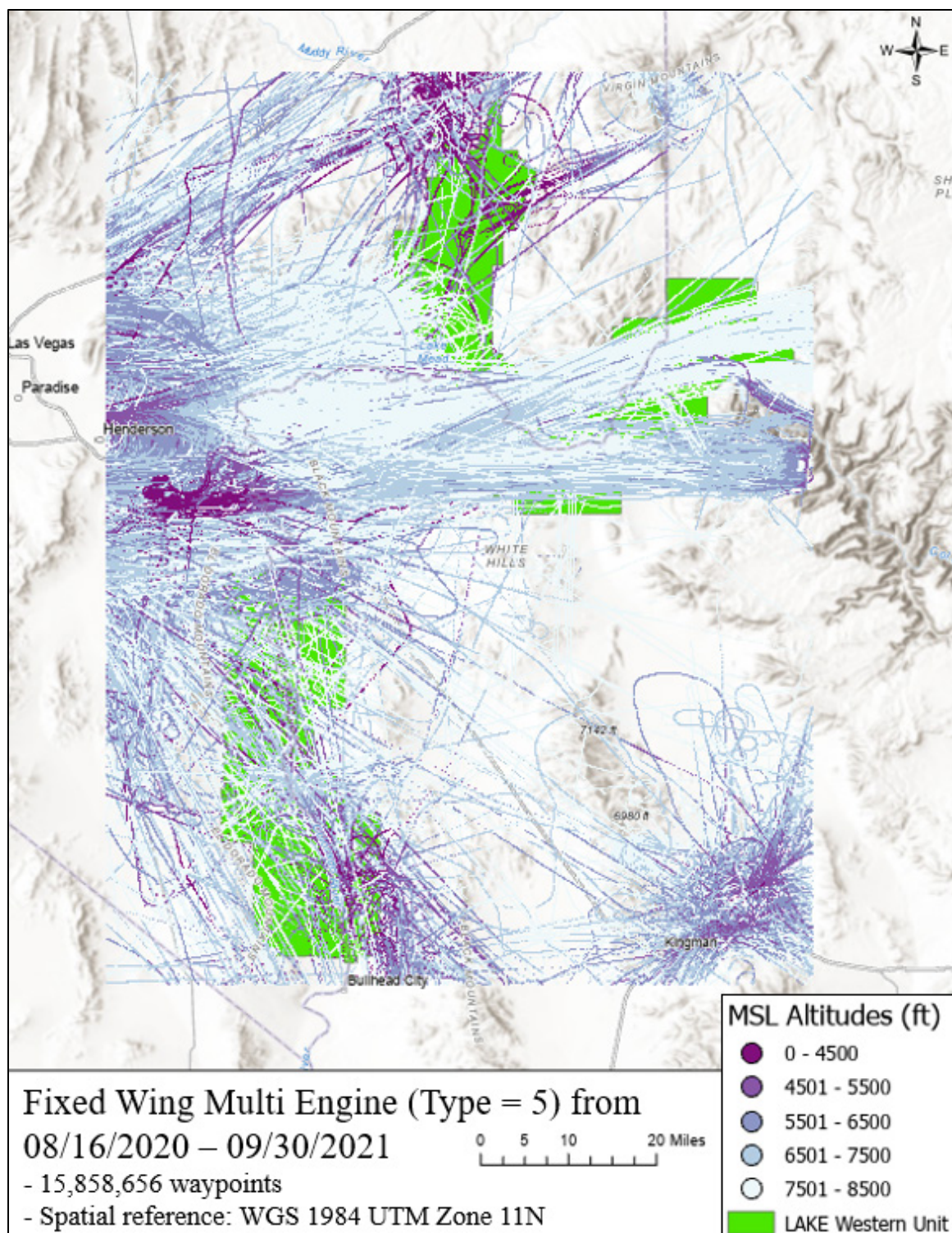


Figure 6. Low-level fixed wing multi engine overflights.

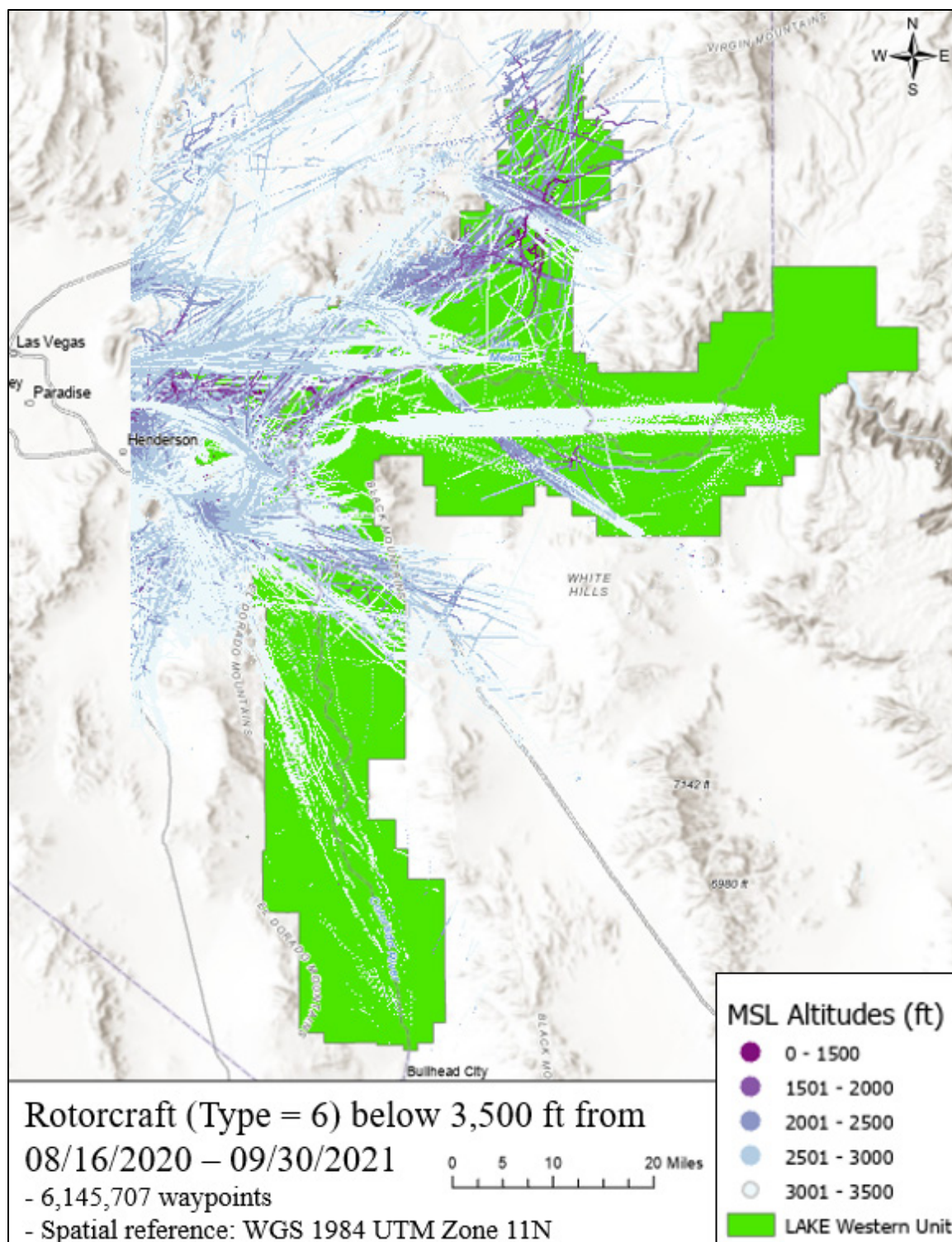


Figure 7. Low-level rotorcraft overflights that flew at altitudes between 0–3,500ft MSL.

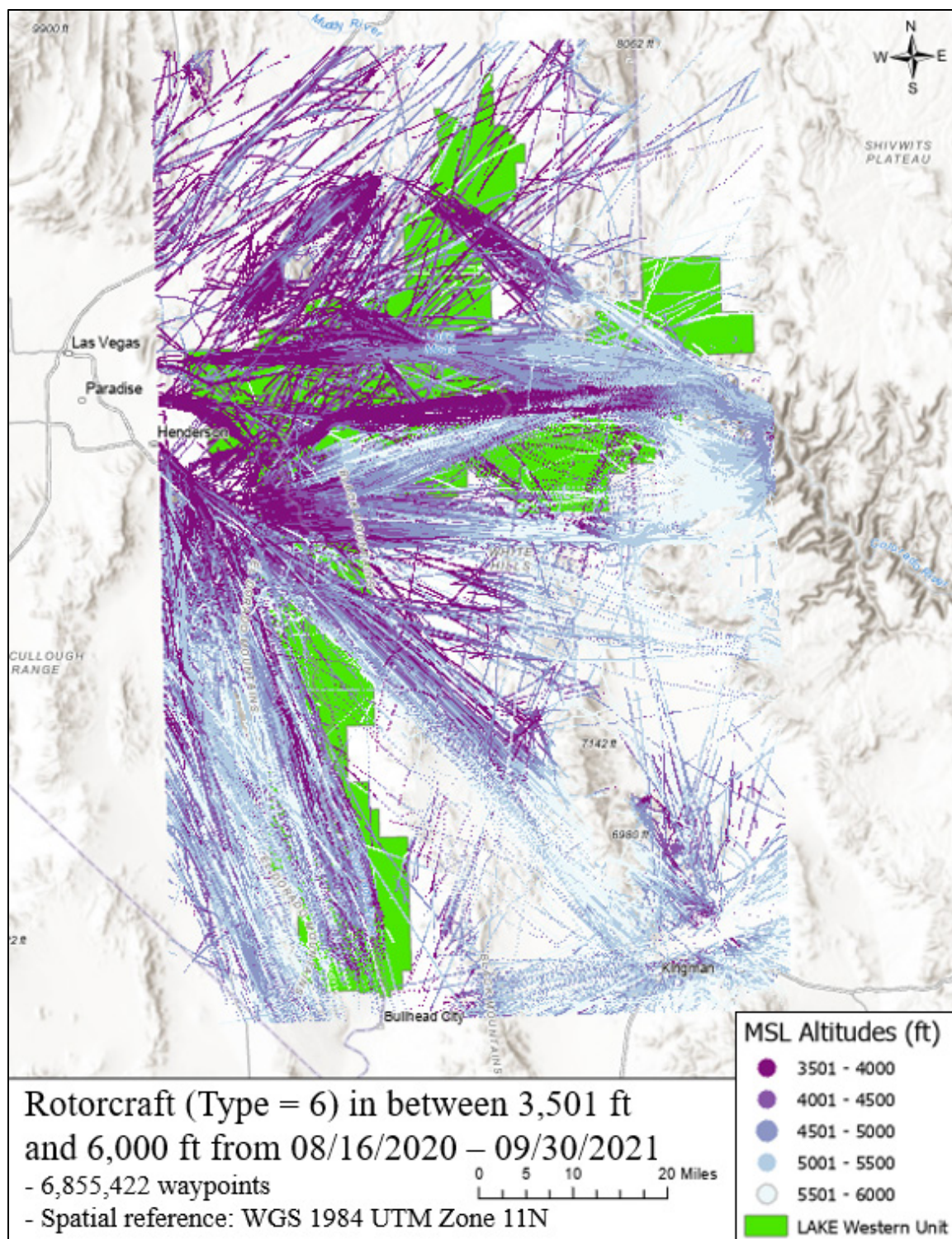


Figure 8. Low-level rotorcraft overflights that flew at altitudes between 3,501–6,000ft MSL.

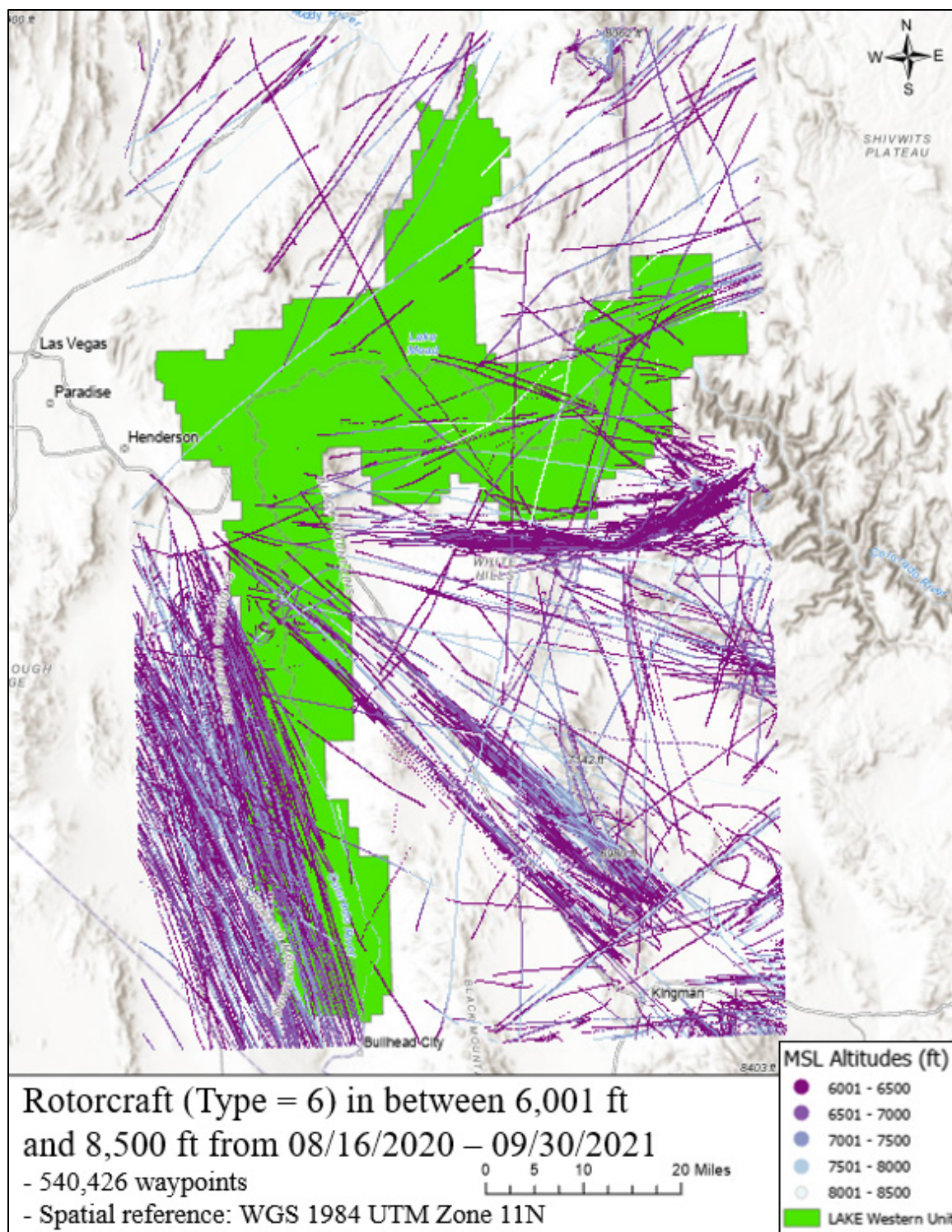


Figure 9. Low-level rotorcraft overflights that flew at altitudes between 6,001–8,500ft MSL.

Results – Phase 3

Data were cleaned for civil patrol flights, survey flights, and flights with straight-line paths, which resulted in the following numbers of flights removed: 1,209 civil patrol flights, 367 survey flights, and 373,496 flights with straight-line paths. Next, kernel density analysis was conducted across AGL altitude intervals. The AGL altitude interval that showed the most density was 4,000–4,500ft (Figures 10, 11). The density outputs were statistically compared using a correlation test. The altitude intervals with the highest correlation were 2,500–3,000ft AGL and 3,00–3,500ft AGL (Table 1).

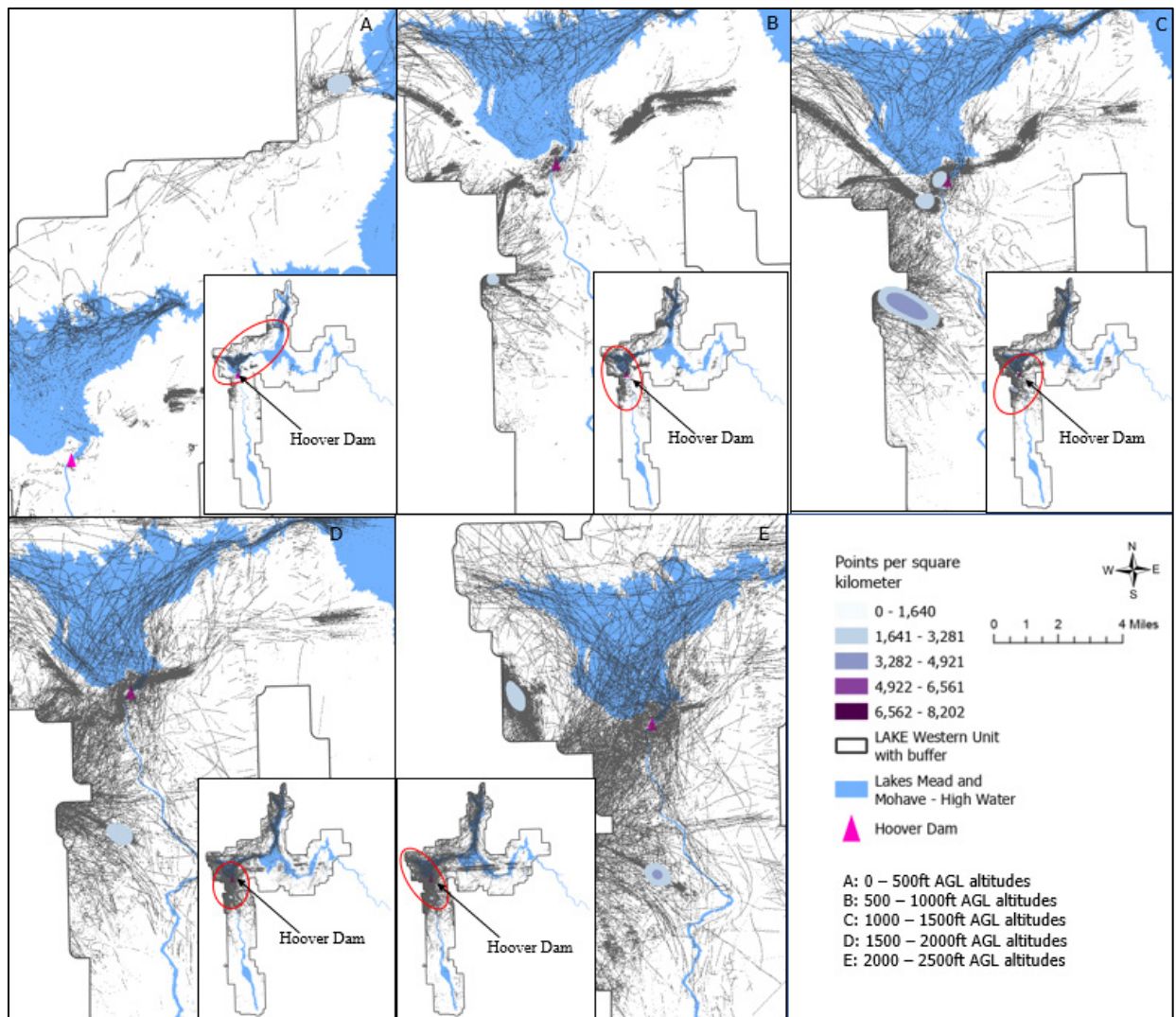


Figure 10. Kernel density analysis across AGL altitude intervals ranging from 0–2,500ft AGL.

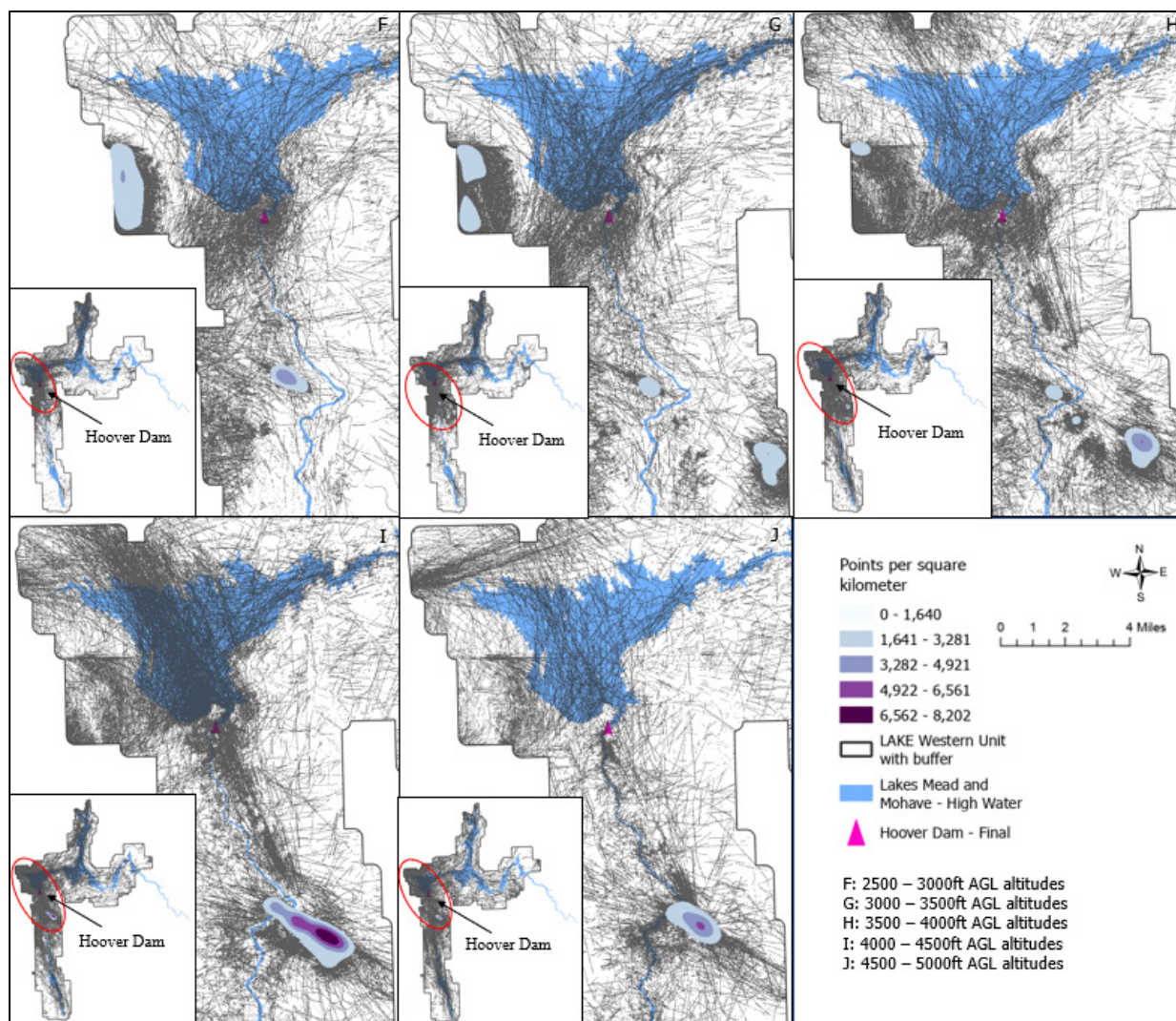


Figure 11. Kernel density analysis across AGL altitude intervals ranging from 2,500–5,000ft AGL.

Table 1. Spatial correlation matrix of AGL altitude kernel densities.

AGL Altitude Interval	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. 0–500ft AGL	–	–	–	–	–	–	–	–	–
2. 500–1,000ft AGL	0.64	–	–	–	–	–	–	–	–
3. 1,000–1,500ft AGL	0.21	0.56	–	–	–	–	–	–	–
4. 1,500–2,000ft AGL	0.17	0.38	0.72	–	–	–	–	–	–
5. 2,000–2,500ft AGL	0.16	0.30	0.41	0.66	–	–	–	–	–
6. 2,500–3,000ft AGL	0.12	0.24	0.27	0.39	0.78	–	–	–	–
7. 3,000–3,500ft AGL	0.14	0.27	0.32	0.43	0.61	0.79	–	–	–
8. 3,500–4,000ft AGL	0.10	0.22	0.28	0.38	0.43	0.52	0.72	–	–
9. 4,000–4,500ft AGL	0.09	0.14	0.16	0.25	0.25	0.24	0.35	0.55	–
10. 4,500–5,000ft AGL	0.07	0.11	0.14	0.22	0.21	0.18	0.26	0.42	0.77

To further understand altitude trends of waypoints, two visualizations were produced. Figures 12 (altitudes ranging from 0–2,500ft AGL) and 13 (altitudes ranging from 2,500–5,000ft AGL) display AGL altitude trends directly above Lake Mead and show variability in flight altitudes. Figure 14 displays MSL altitude trends directly above Lake Mead and shows waypoint trends were mostly above 3,500ft MSL. The information displayed in Figures 12, 13, and 14 were inputted into tables to quantitatively understand which altitude intervals had the highest percentage of waypoints (2,863,363 waypoints were analyzed). The AGL altitude interval that received the highest percentage of waypoints was 4,000–4,500ft (Table 2). The MSL altitude interval that received the high percentage of waypoints was 5,500–6,500ft (Table 3).

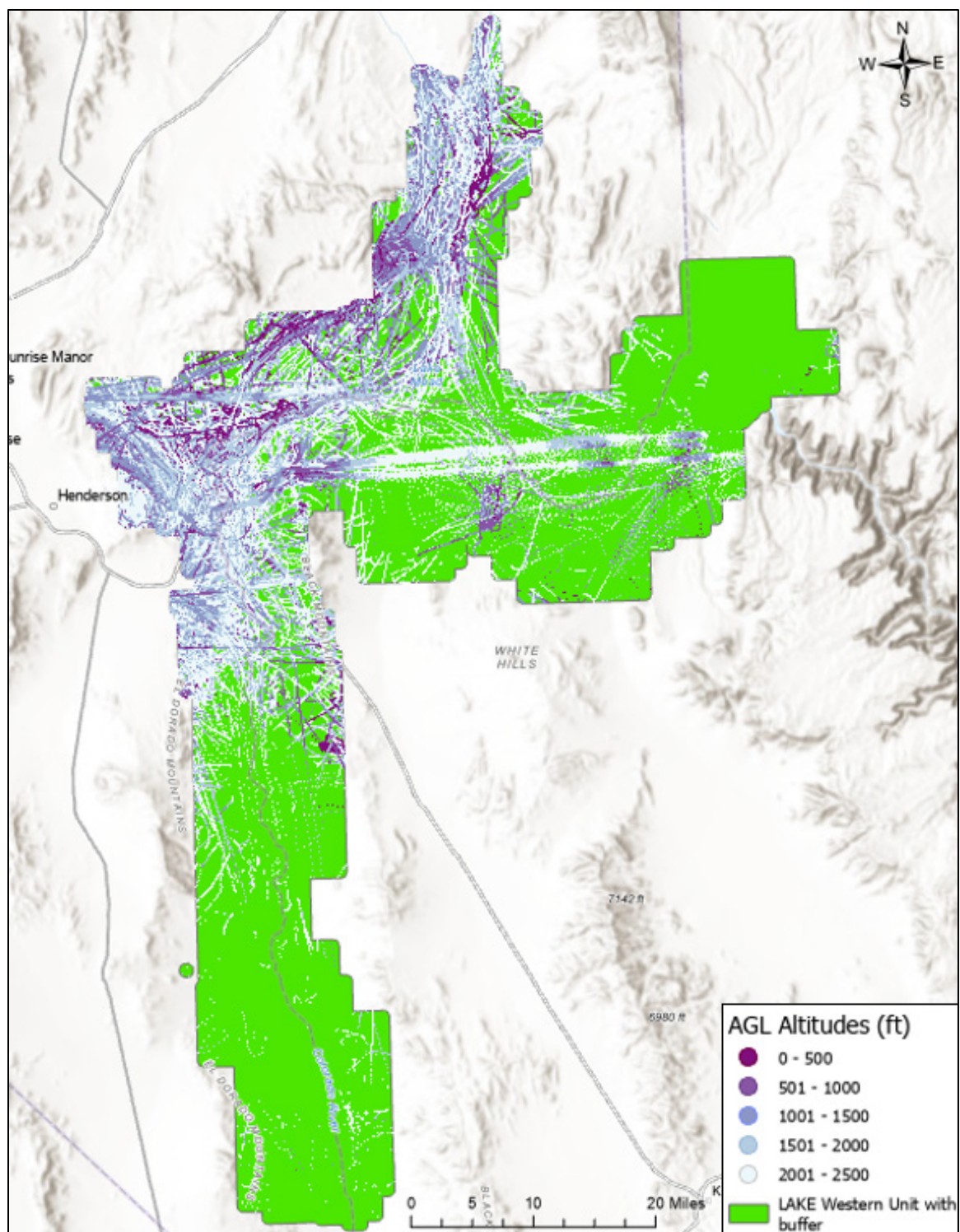


Figure 12. AGL altitude trends of altitudes ranging from 0–2,500ft AGL for waypoints within 0.5 mile of Lake Mead National Recreation Area boundary ($n=916,125$ waypoints).

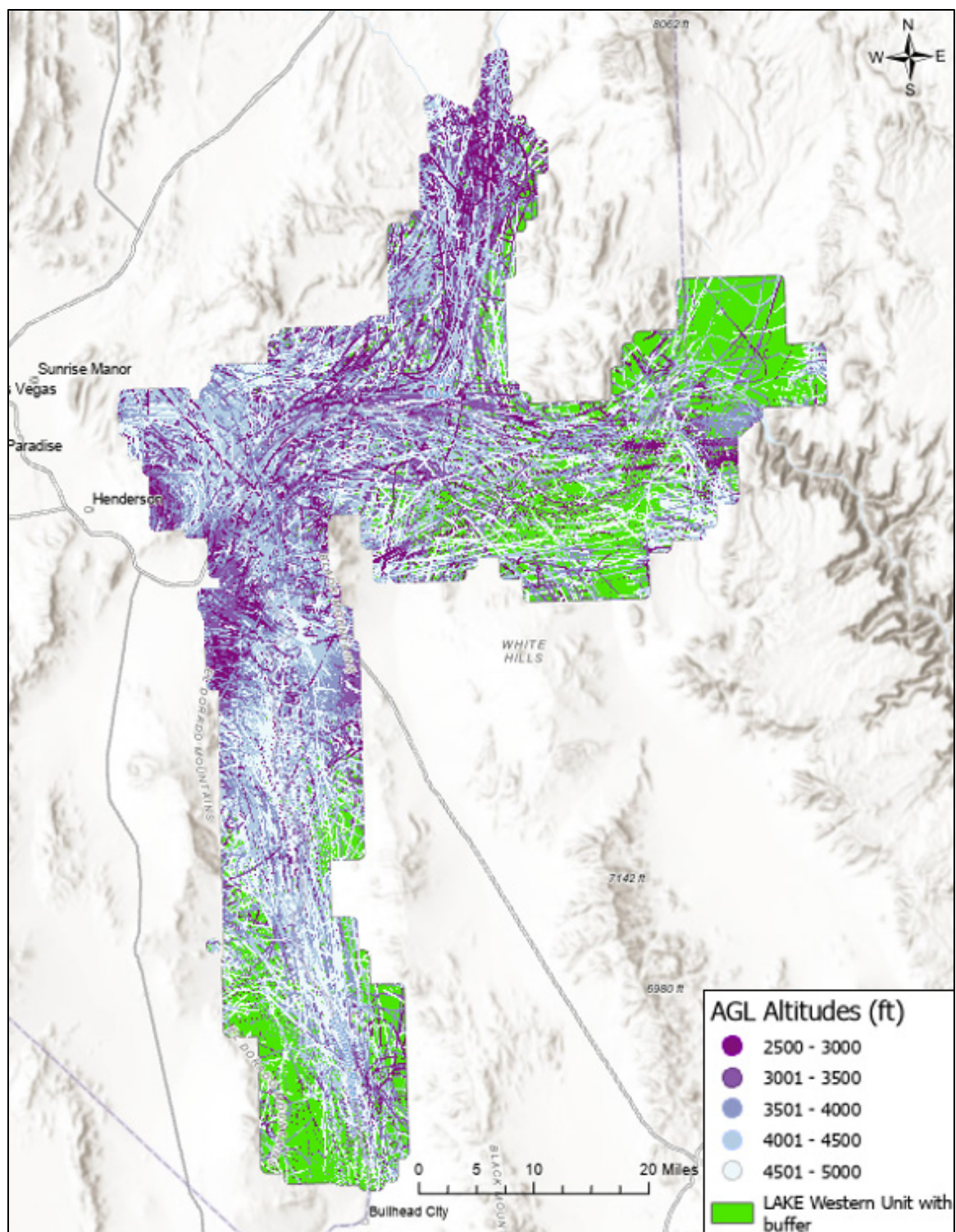


Figure 13. AGL altitude trends of altitudes ranging from 2,500–5,000ft AGL for waypoints within 0.5 mile of Lake Mead National Recreation Area boundary ($n=1,948,724$ waypoints).

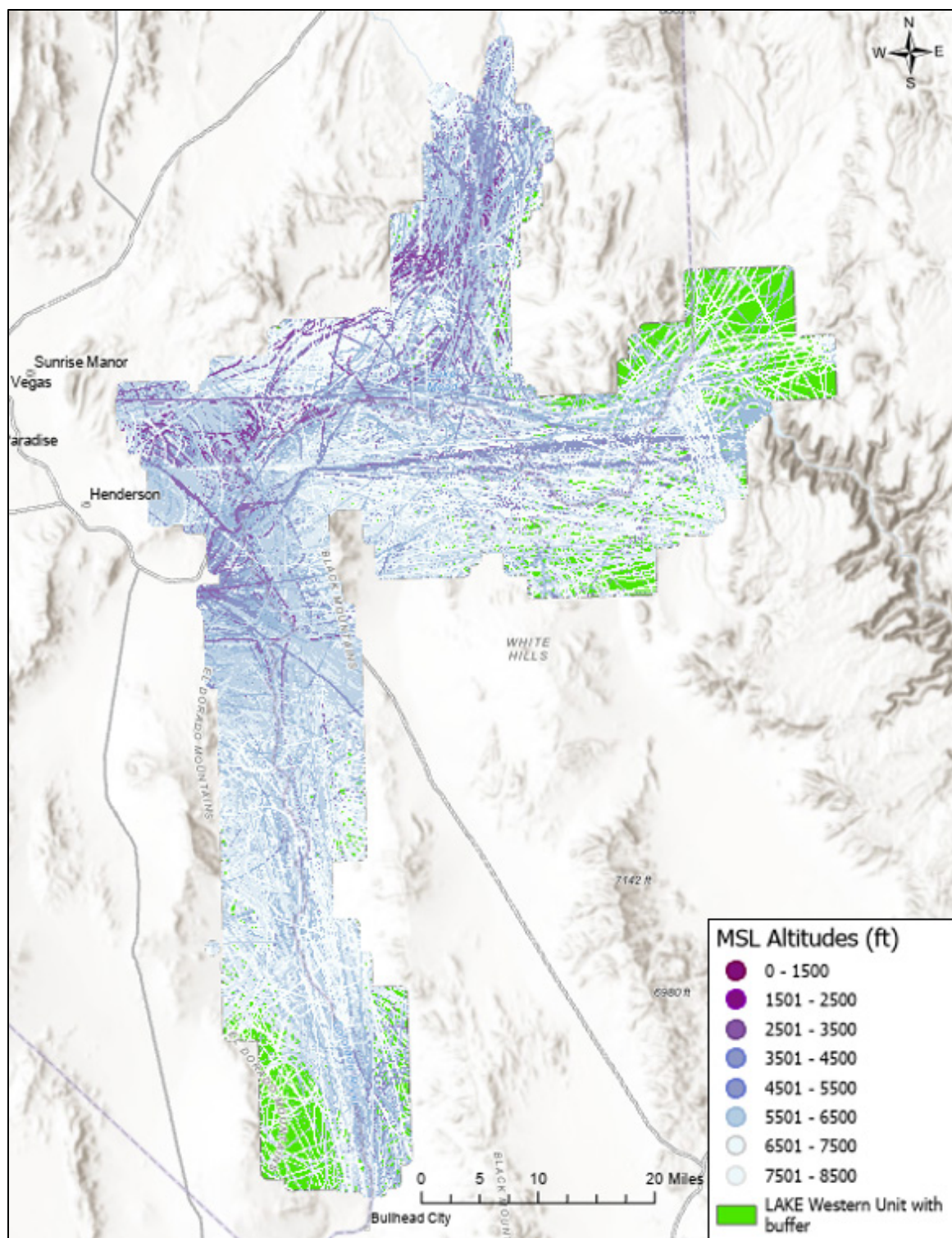


Figure 14. MSL altitude trends of altitudes ranging from 0–8,500ft MSL for waypoints within 0.5 mile of Lake Mead National Recreation boundary ($n=3,659,086$ waypoints).

Table 2. Number and percentage of waypoints across AGL altitude intervals ($n=2,863,363$).

AGL altitude	Number of waypoints	Percentage of waypoints
0–500ft	79,496	2.78
501–1,000ft	154,809	5.41
1,001–1,500ft	237,319	8.29
1,501–2,000ft	197,030	6.88
2,001–2,500ft	247,541	8.65
2,501–3,000ft	317,779	11.10
3,001–3,500ft	380,177	13.28
3,501–4,000ft	389,088	13.59
4,001–4,500ft	527,584	18.43
4,501–5,000ft	332,540	11.61

Table 3. Number and percentage of waypoints across MSL altitude intervals ($n=3,659,086$).

MSL altitude	Number of waypoints	Percentage of waypoints
0–1,500ft	39,195	1.07
1,501–2,500ft	160,473	4.39
2,501–3,500ft	364,720	9.97
3,501–4,500ft	529,130	14.46
4,501–5,500ft	756,459	20.67
5,501–6,500ft	957,851	26.18
6,501–7,500ft	503,756	13.77
7,501–8,500ft	347,484	9.50

Lastly, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 12,669). Table 4 shows number of days air tour data were collected, overflights per month, average number of flights per day for the data collection duration, which occurred from August 16th of 2020 to September 30th of 2021. LAKE received the most overflights between March of 2021 to September of 2021; for this duration average number of flights ranged between 33.39 to 43.71. Figure 15 shows average numbers of flights across days of the week where n is the number of weekdays sampled. The most overflights occurred on Thursdays (average number of flights was 34.32), Fridays (average number of flights was 36.71), Saturdays (average number of flights was 33.05), and Sundays (average number of flights was 33.58). Table 5 shows number and percentage of overflights per hour across weekdays (Monday through Friday) and weekends (Saturday, Sunday, and holidays). LAKE received the most overflights during the hours of 10:00am to 12:00pm.

Table 4. Number and percentage of overflights across months ($n=12,669$).

Month	Number of data collection days	Number of overflights	Average Number of overflights
August 2020*	16	342	21.38
September 2020	30	705	23.50
October 2020	31	701	22.61
November 2020	30	754	25.13
December 2020	30	632	21.07
January 2021	31	678	21.87
February 2021	28	705	25.18
March 2021	31	1,035	33.39
April 2021	30	1,086	36.20
May 2021	30	1,157	38.57
June 2021	29	1,190	41.03
July 2021	31	1,355	43.71
August 2021	31	1,137	36.68
September 2021	28	1,192	42.57

* For August of 2020, data collection began on August 15th; for May of 2021, data collection ended on May 15th.

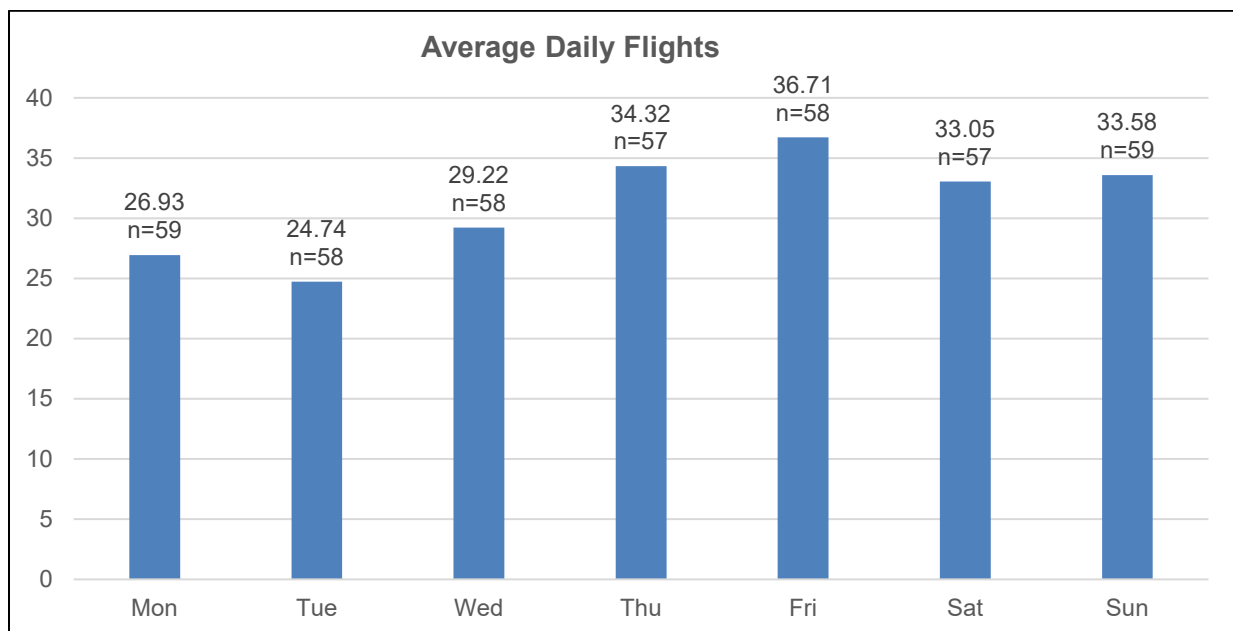


Figure 15. Average number of flights per day of the week.

Table 5. Number and percentage of overflights across hours of the day for weekdays ($n=7,379$) and weekends ($n=3,336$).

Hour	Weekdays number of overflights	Weekdays percentage of overflights	Weekends number of overflights	Weekends percentage of overflights
6:00am–7:00am	106	1.20	28	0.72
7:00am–8:00am	182	2.07	84	2.17
8:00am–9:00am	407	4.62	208	5.38
9:00am–10:00am	567	6.44	300	7.76
10:00am–11:00am	850	9.65	411	10.63
11:00am–12:00pm	793	9.01	375	9.70
12:00pm–1:00pm	698	7.93	317	8.20
1:00pm–2:00pm	722	8.20	341	8.82
2:00pm–3:00pm	614	6.97	320	8.28
3:00pm–4:00pm	605	6.87	294	7.61
4:00pm–5:00pm	572	6.50	240	6.21
5:00pm–6:00pm	458	5.20	168	4.35
6:00pm–7:00pm	424	4.82	130	3.36
7:00pm–8:00pm	381	4.33	120	3.10

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at LAKE. Flight tracking data were analyzed from August 16th, 2020 to September 30th, 2021 and included 387,741 overflights. Analysis consisted of three phases.

The first phase focused on all overflights and showed a concentrated trend of overflights above LAKE. Visual analysis of these data suggests overflights commonly fly within corridors.

The second phase focused on low-level overflights and showed variability across aircraft types (fixed wing single engine, fixed wing multi engine, rotorcraft).

The third phase attempted to focus more specifically on air tours by removing flights known to not be air tours. The dataset was cleaned of 1,209 civil patrol flights, 367 survey flights, and 373,496 flights with straight-line paths. It was found that overflight density was the highest for the altitude interval of 4,000–4,500ft AGL, which also had the most waypoints of the analyzed altitude intervals. Air tours more uncommon at these altitudes, which suggest that this phase 3 data set may have included many flights that were not air tours. Regardless, these lower level flights produce more intense noise than higher altitude flights for on the ground resources and visitors' experiences.

In conclusion, this study produced results to further understand overflights at LAKE. This information can be used for planning and management purposes. This study serves as a resource for future research that intends to use more advanced analytics.

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